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Hydrometeorological conditions for the Miramichi River basin during 1994[2]

by

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[1]This series documents the scientific basis for the evaluation of fisheries resources in Atlantic Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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[1]La présente série documente les bases scientifiques des évaluations des ressources halieutiques sur la côte atlantique du Canada. Elle traite des problèmes courants selon les échéanciers dictés. Les documents qu'elle contient ne doivent pas être considérés comme des énoncés définitifs sur les sujets traités, mais plutôt comme des rapports d'étape sur les études en cours.

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[2]Contribution #16 of the Catamaran Brook Habitat Research Project.

ABSTRACT

The objective of the present paper is to provide information on the hydrological and meteorological conditions within the Miramichi River basin during 1994. A discussion is also provided as to how some of these environmental factors could have affected Atlantic salmon (*Salmo salar*) populations both at the juvenile and adult stage during this past year.

Most of the meteorological information during 1994 comes from the weather station in the Catamaran Brook basin. Hydrometric data (1965-1993) and long-term meteorological data (1969-1993) were provided by Environment Canada. Stream water temperatures were obtained from Catamaran Brook, Northwest Miramichi River, Southwest Miramichi River, Little Southwest Miramichi and Dungarvon Rivers (Marine and Anadromous Fish Division, DFO, Moncton).

Below normal air temperatures were recorded in early winter (January) within the Miramichi. An important ice run occurred during mid-April in parts of the Miramichi River system apparently triggered by high air temperatures. This ice run resulted in ice jams particularly on the Renous and the Little Southwest Miramichi Rivers. pH depression during spring runoff reached 6.0 in Catamaran Brook, a relatively well buffered stream with higher alkalinity and conductivity than other streams in the region, such as the Little Southwest Miramichi River. High air temperatures were monitored July 22 with a daily mean of 25.2 °C, followed by high stream water temperatures July 24 at Catamaran Brook (21.1 °C), the highest since 1990 (beginning of monitoring of water temperatures at Catamaran Brook). Low flow conditions within the Miramichi River basin in September and October 1994 ranged from a 5-year low flow in the Northwest Miramichi River to an estimated 50-year low flow in Renous River.

RÉSUMÉ

Le présent article a pour objet de fournir de l'information sur les conditions hydrologiques et météorologiques qui ont prévalu dans le bassin versant de la rivière Miramichi au cours de l'année 1994. On y discute également des incidences que certains de ces facteurs environnementaux auraient pu avoir sur les populations de saumon de l'Atlantique (*Salmo salar*) - juvéniles et adultes - au cours de la dernière année.

La plupart des données météorologiques recueillies en 1994 proviennent de la station météorologiques située dans le bassin versant du ruisseau Catamaran. Les données hydrométriques (de 1965 à 1993) et les données météorologiques à long terme (de 1969 à 1993) ont été fournies par Environnement Canada. La Division des poissons de mer et des espèces anadromes du MPO, Moncton, a fourni des données sur la température de l'eau du ruisseau Catamaran, de la rivière Northwest Miramichi, de la rivière Southwest Miramichi, de la rivière Little Southwest Miramichi et de la rivière Dungarvon.

Dans le bassin versant de la rivière Miramichi, on a enregistré des températures de l'air inférieures à la normale en début d'hiver (janvier). On a observé une importante descente des glaces à la mi-avril dans certaines parties du bassin versant de la rivière Miramichi, provoquée apparemment par les températures élevées de l'air. Cette descente a provoqué des embâcles, particulièrement sur la rivière Renous et sur la rivière Little Southwest Miramichi. Au cours de l'écoulement printanier, la dépression du pH a atteint 6,0 dans le ruisseau Catamaran, un cours d'eau relativement bien tamponné et où l'alcalinité et la conductibilité sont plus élevées que dans d'autres cours d'eau de la région, notamment la rivière Little Southwest Miramichi. Le 22 juillet, on a enregistré des températures maximales de l'air, la moyenne pour la journée ayant atteint 25,2 °C. Puis le 24 juillet, on a enregistré des températures maximales de l'eau dans le ruisseau Catamaran, à 21,1 °C. Le ruisseau Catamaran n'a pas connu de température aussi élevée depuis 1990, date où on a commencé à mesurer la température de l'eau au ruisseau Catamaran. En septembre et octobre 1994, on a observé un faible débit dans le bassin versant de la rivière Miramichi, allant d'un intervalle de récurrence de cinq ans dans la rivière Northwest Miramichi à un débit faible d'un intervalle de récurrence de plus de 50 ans dans la rivière Renous.

Introduction

The objective of this paper is to provide meteorological and hydrological data and analysis within the Miramichi River drainage basin for 1994. In general, the year 1994 was characterized by major ice jamming during the spring breakup. Later during the summer, high stream water temperatures and low flow conditions were recorded; some rivers had a 50-year low flows.

Recent air temperature data (1990 - 1994) from the primary meteorological station at Catamaran Brook within the Miramichi River basin are presented. Long-term historical data on air temperature and precipitation have been collected from the nearby McGraw Brook meteorological station which is the most centrally located station within the Miramichi River basin (Figure 1). Recent data on stream discharge came from both Environment Canada hydrometric station network and from the Catamaran Brook basin. Discharge data during the summer of 1994 are however still provisional and final results may differ slightly. Data on stream water temperature were available from Catamaran Brook and from three other rivers (Northwest Miramichi, Southwest Miramichi, and Dungarvon; see Figure 1) collected by the Department of Fisheries and Oceans (Marine and Anadromous Fish Division) at different traps.

Meteorological Conditions

Annual precipitation data for the Miramichi River basin were obtained from the meteorological station at McGraw Brook and from Catamaran Brook. Data at McGraw Brook have been collected by the Department of Natural Resources (DNR) station since 1969. The measured precipitation ranged from 860 mm to 1365 mm, with a long-term average of 1142 mm (Cunjak et al. 1993). Long-term monthly precipitation within the Miramichi basin is evenly distributed at approximately 100 mm per month (Cunjak et al. 1993).

Long-term data for mean monthly air temperatures were also obtained from the McGraw Brook meteorological station. January is the coldest month with a long-term mean temperature of -11.8 °C. July is the warmest month with a mean monthly temperature of 18.8 °C (Table 1). Recent data are also presented to show the variability in air temperatures over the years. January of 1994 was the coldest January since 1969 with a monthly mean temperature of -16.4 °C which was 4.6°C colder than long-term average of -11.8 °C (Table 1). February and May were also markedly colder compared with the long-term average. Whereas, June and July experienced above normal temperatures (Table 1).

During the winter of 1994, the coldest hourly recorded temperature since 1990 occurred January 20, measured at -38.1 °C with a daily mean of -26.9 °C (Figure 1). During late January and February two different thaw events were recorded. The first occurred January 29 when the maximum hourly temperature reached 7.4 °C; then, on February 20, a maximum hourly temperature of 16.0 °C with a daily mean of 5.3 °C was recorded (Figure 1).

The spring ice-breakup in mid-April, 1994, was characterized as a premature breakup triggered by high daily mean temperatures April 15-17 (11.6 °C, 8.2 °C, and 9.7 °C; Figure 1). Maximum hourly temperatures of 19.2 °C and 21.2 °C were recorded on April 15 and 16, respectively. Major ice jams and ice runs were observed during this period; further details of this event are provided below.

The maximum daily mean air temperature at Catamaran Brook in 1994 was 25.2 °C, recorded July 22 (day 203; Figure 1) while the maximum hourly air temperature was recorded the day before, July 21 at 31.7 °C. Such high air temperatures had a significant impact on the stream water temperatures in the Miramichi region because the two variables tend to be highly correlated.

Also of importance to aquatic habitat and biota was the precipitation during 1994 and especially during the summer when a lack of precipitation resulted in reduced stream discharge. The precipitation during May was above normal at 179.8 mm, but, below the maximum recorded precipitation of 196.7 in 1979 (Table 2). June showed slightly above normal precipitation while July and September showed slightly below values. Precipitation during, August and October were below normal with only 23.1 mm and 30.2 mm, respectively (Table 2).

Hydrological Conditions

The most recent discharge data for Catamaran Brook (station 01BP002), measured at the hydrometric station 7 km above the river mouth are presented in Table 3. The long-term data were calculated using prorated values from the nearby Renous River at McGraw Brook (station 01BO002). Streamflow conditions in the Miramichi River basin, based on the Catamaran Brook data, were close to normal during the winter and spring of 1994 (Table 3). However, extremely low monthly flows were monitored during July, August, September and October of this year (Table 3). The lowest monthly flows for September and October since 1965 (0.070 m^3/s and 0.078 m^3/s respectively) were recorded in 1994.

Below normal air temperatures in January coupled with a significant thermal input in April within the Miramichi River basin resulted in one of the largest premature ice-breakup events in years throughout the Miramichi River system during mid-April, 1994. This premature breakup resulted in major ice jamming and ice scouring in the lower 1 km of Catamaran Brook, in the Little Southwest Miramichi River, and in the Renous River (per. obser.). High water levels behind a major ice jam were recorded at the confluence of Catamaran Brook and on the Little Southwest Miramichi River. Stream-side ice walls of approximately 8 m were observed on the Little Southwest Miramichi River. The ice jams and subsequent scouring of mid-April 1994 could have affected redds and fish in many river systems including the Little Southwest Miramichi River where significant bedload movement was noted and newly created pools were observed. A layer of deposited fine materials (detritus, sediment) was observed throughout the river flood plain below high water marks, suggesting that the concentration of suspended sediments was quite high. In fact, during the spring breakup of 1994 on the Saint John river system, suspended sediment concentrations of between 100 and 150 mg/l were monitored (S. Beltaos, pers. comm.). He (S. Beltaos) also monitored brief concentration spikes of between 300 and 800 mg/l during surges caused by ice jam releases. Following this premature ice-breakup, no major floods were recorded in the Miramichi River during the typical high flow season (Apr. to early May).

The results for daily discharge were similar to monthly values with very low flow conditions in late summer and fall (Figure 2). The lowest discharge at Catamaran Brook during 1994 was measured September 4 (day 247, Figure 2) at approximately 0.022 m^3/s, the lowest recorded discharge at that station. This low discharge was estimated to be a 10-year low flow. Within the Miramichi River basin, other rivers also experienced low flows; but of varying magnitude. For instance, the Northwest Miramichi River experienced (September 2) a 5-year low flow while Renous River was the most severely affected, measuring a low flow with an estimated 50-year recurrence interval. Such a low flow situation in late summer and during the fall could have had some adverse effects on fish populations, especially migratory fishes. For example, in Catamaran Brook the low flow situation coupled with the construction of a beaver dam approximately 1 km from the mouth of the brook prevented upstream movement by most adult Atlantic salmon.

Water chemistry

During the spring breakup of 1994, pH and conductivity were measured at Catamaran Brook to monitor the extent of pH depression and corresponding conductivity. Results at Catamaran Brook showed that pH was highly variable during the spring breakup and two major pH depressions were observed, one on April 17, and one on May 13, 1994 (Figure 3). The pH depression of April 17, 1994 (day 107) was due to the first snowmelt of the season triggered by the same warm temperatures which resulted in the premature ice-breakup. For that particular event, pH decreased to a low of 5.99 pH units. The second pH depression (May 13) occurred during a high discharge event, which was the result of a combination of rainfall and snowmelt. Between May 12 and 13 a total of 56 mm of rain was recorded at Catamaran Brook. The discharge in the Middle Reach of Catamaran during this period peaked at approximately 11 m^3/s with a corresponding peak suspended sediment concentration of approximately 174 mg/l. pH decreased to 6.06, while the conductivity decreased to 16.4 µS/cm. Following the May 13 event, pH and conductivity recovered to mean values in approximately 10 days (Figure 3). A good relationship was found between pH and conductivity during the depression and recovery period (Figure 3). Similar recovery periods of 10 days during summer pH depressions were observed by Caissie et al. (1994), however, at higher pH values. Although the spring pH depression in Catamaran Brook was found at approximately 6.0, water chemistry data from other rivers (Caissie, Unpubl. data) within the Miramichi River basin show that they could have potentially lower pH values during the spring. For example, a pH of 5.3 was measured in the Little Southwest Miramichi River in May 1991. Low pH during the spring runoff can negatively affect the survival of eggs and alevins (Lacroix 1985), especially as these events are often associated with higher levels of aluminium (Al) which is reported to be harmful to fish (Campbell et al. 1992).

Stream Water temperatures

Stream water temperatures during the early part of the season (from April 28, day 118 to May 20, day 140) were below normal in Catamaran Brook (Figure 4). In general, within the Miramichi River basin, the maximum stream water temperature usually occurs at the end of July (Fourier curve, day 210 = July 29; Figure 4). In 1994, stream water temperature in Catamaran Brook was above normal from mid-June to early August (Figure 4). The maximum daily mean stream water temperature was reached on July 24 (day 205) at 21.1 °C. This value represents the highest daily mean water temperature measured in Catamaran Brook since 1990 (Figure 4).

In order to study the differences between small and larger river systems, stream water temperature measured on the Southwest Miramichi, Northwest Miramichi, Dungarvon, and at Catamaran Brook were analyzed and compared. In the analysis of stream water temperatures, the model suggested by Cluis (1972) was used for the above rivers. This model separates stream water temperatures into two components, namely the long-term variation represented by a Fourier series and a short-term component represented by a second order Markov process (Cluis 1972). The long-term component represents the seasonal variation of water temperature from 0 °C in the spring to a maximum value in late July before returning to 0 °C in late November. The short-term component, also called the residual, represents the departure from the long-term component during one particular year as a result of above or below normal air temperatures.

Therefore, the stream water temperature, Tw(t), of any given river systems can be represented by these two components, the long-term seasonal component, T(t), and the short-term residuals, Re(t), such as:

$$Tw(t) = T(t) + Re(t) \qquad \textbf{(1)}$$

The long-term seasonal component was calculated for the different rivers systems in the Miramichi River basin by the following equation:

$$T(t) = a + b\sin\left(\frac{2\pi}{365}(t-120)\right) \qquad \textbf{(2)}$$

where T(t) is the long-term seasonal component of water temperature, a and b are coefficients depending on the river system, and t represents the day of year (e.g. July 1 = 182). The short-term residuals were calculated using the following equation (Cluis 1972):

$$Re(t) = A_1\,Re(t-1) - A_2\,Re(t-2) + k\,Ra(t) \qquad \textbf{(3)}$$

where Re(t) is the stream water temperature residual at time t, Re(t-1) at time t-1 and Re(t-2) at time t-2. A_1 and A_2 are the coefficients of second order Markov process calculated by (Salas et al. 1980):

$$A_1 = \frac{R_1(1-R_2)}{1-R_1^2} \quad ,while \quad A_2 = \frac{R_2-R_1^2}{1-R_1^2} \qquad \textbf{(4)}$$

with R_1 and R_2 being the autocorrelation coefficient for one and two days respectively. Ra(t) represents the air temperature residual similar to the stream water temperature residuals, while k is an optimized thermal exchange coefficient and dependent on the stream or river. According to Cluis (1972), the autocorrelation coefficients are similar when studying a particular region, because the natural variation in stream water temperature between systems follow each other. Only the thermal exchange coefficient changes between rivers and it is dependent on the stream cover (vegetation), depth of water, groundwater inputs. Therefore, the autocorrelation coefficients calculated at Catamaran Brook (R_1 = 0.709 and R_2 = 0.356) were used throughout the Miramichi basin for predicting river or stream water temperatures. The coefficients of second order Markov process (A_1 and A_2; equation 4) for the Miramichi River basin were then calculated at 0.919 and at -0.294. The optimized value of k as well as the coefficient for the long-term seasonal component of different rivers are given in Table 4. This table shows that the Southwest and Northwest Miramichi Rivers were adequately represented by the same temperature model. These last two sites were in a zone with some tidal influences, however, very little difference was observed between bottom and surface water temperatures during this past summer. For the present study, only the surface water temperatures were used.

Relatively good agreement was obtained between predicted and measured water temperatures for the different river systems (Figure 5). Catamaran Brook recorded lowest water temperatures; maximum values were similarly recorded in Northwest and Southwest Rivers (Figure 5). In general, smaller streams have cooler summer water temperatures as a result of less exposure to heating. Also smaller streams such as Catamaran Brook have a significant and relatively greater groundwater input.

It was observed that the maximum daily air temperature was reached a few days before the stream and rivers reached their maximum. Catamaran Brook and Dungarvon River reached their maximum water temperatures 2 days after maximum air temperature was recorded; the Northwest and Southwest Rivers reached their peaks 4 days after air temperature maxima (Table 5). The highest daily mean water temperature was recorded on the Southwest Miramichi River at 25.4 °C, July 26 (day 207). However, the maximum recorded temperature came from the Little Southwest Miramichi at 28.0 °C. Data from the Little Southwest Miramichi were obtained from a manual gauge just above the confluence of Catamaran Brook. It is important to note that water temperatures are site specific and would change downstream and upstream of the rivers sites. Daily variation in stream water temperatures was also measured for the different rivers. The greatest difference (maximum - minimum) was measured on the Dungarvon and Little Southwest Miramichi Rivers at 4.5 °C and 6.0 °C respectively (Table 5). The Northwest Miramichi River showed the smallest diel temperature difference (1.5 °C).

Stream water temperatures in the range of 23 - 25 °C have been observed to result in salmonid mortality (Lee and Rinne 1980, Bjornn and Reiser 1991). During such high stream water temperatures, instream movements of fish into colder small tributary streams have been observed within the Miramichi River basin (Cunjak et al. 1993).

Summary

In summary, during 1994 many environmental conditions could have affected stream biota and in particular salmonid populations within the Miramichi River basin. First, the ice run of April 15 could have had some scouring effects on redds as well as some possible high suspended sediment concentrations. Secondly, the measured pH depression during spring runoff showed that pH values of approximately 6.0 pH units were observed in Catamaran Brook. Catamaran Brook is a relatively well-buffered stream with higher alkalinity and conductivity than other streams in the region, namely the Little Southwest Miramichi River. High stream water temperatures were monitored late July of this year and the observed value was the highest since 1990, when monitoring began at Catamaran Brook. Low flow conditions in September may have reduced juvenile habitat and restricted upstream movement of adult salmon. In Catamaran Brook many adult salmon spawned in the lower first km of the brook due to low flows and a newly-created beaver dam.

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Table 1. Monthly mean air temperature recorded in Catamaran Brook (1990 - 1994) compared to the long-term average from McGraw Brook meteorological station (1969-92).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					Mean monthly temperature (°C)							
1990	-10.3	-14.4	-5.9	2.5	8.4	16.7	18.8	19.9(+)	11.8	7.4	0.4	-6.0
1991	-14.0	-9.6	-2.0	3.3	11.0	16.2	18.5	18.9	11.6	6.9	1.6	-11.4
1992	-11.6	-15.3	-6.1	2.8	11.0	15.5	16.1(-)	17.7	14.1	7.0	-1.0	-1.8(+)
1993	-11.6	-14.6	-4.4	3.2	10.0	14.7	17.3	18.0	12.5	3.7	-1.1	-5.9
1994	-16.4 (-)	-12.8	-3.5	3.1	8.0	17.1	20.0	17.1	11.7	-	-	-
Avg.[1]	-11.8	-10.1	-3.8	2.9	10.1	15.6	18.8	17.7	12.1	6.2	0.0	-8.2

[1] Avg. = long-term monthly average at McGraw Brook meteorological station from 1969 to 1992.
(+) maximum monthly recorded air temperature (1969-1994).
(-) minimum monthly recorded air temperature (1969-1994).

Table 2. Monthly precipitation (mm) recorded at Catamaran Brook during 1994 compared to the long-term average (1969-92) at McGraw Brook meteorological station data.

Month	Avg.[1]	1994	Maximum[2]	(Year)
May	105.8	179.8	196.7	(1979)
June	95.2	129.3	244.8	(1977)
July	100.8	87.6	192.2	(1980)
August	96.5	23.1	245.2	(1991)
September	96.3	89.4	173.8	(1987)
October	100.4	30.2	238.8	(1977)

[1] Avg. = long-term monthly average from 1969 to 1992.
[2] Maximum = monthly maximum recorded precipitation for the period 1969 to 1994.

Table 3. Mean monthly discharge (m^3/s) measured in the Middle Reach of Catamaran Brook from 1990-1994, and the long-term monthly mean (1965-1990) based on prorated values from nearby Renous River.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	0.224	0.268	0.268	1.90	1.69	0.492	0.361	0.594	0.273	1.09	1.07	1.14
1991	0.486	0.148	0.413	2.18	2.18	0.497	0.135(-)	0.432	0.716(+)	1.12	0.755	0.327
1992	0.253	0.150	0.213	1.13	1.43	0.384	0.479	0.500	0.139	0.458	0.515	0.211
1993	0.170	0.140	0.122	1.67	1.19	1.17	0.441	0.126	0.108	0.479	0.742	0.999
1994	0.356	0.259	0.321	2.11	2.36	0.498	0.136	0.060	0.070(-)	0.078(-)	-	-
1965-90*	0.283	0.354	0.403	1.82	2.15	0.629	0.295	0.256	0.282	0.512	0.658	0.587

* Long-term monthly discharge at Catamaran Brook based on prorated values from Renous River (station 01BO002).
(+) maximum monthly recorded discharge (1965-1994).
(-) minimum monthly recorded discharge (1965-1994).

Table 4. Calculated parameters used for the stream water temperature modelling in the Miramichi River basin. Parameter a and b determine the long-term seasonal component in equation 2 while k is the thermal exchange coefficient used in equation 3 (see text).

River	a	b	k
Catamaran	3.1	12.0	0.196
Dungarvon	3.5	13.5	0.271
Southwest	4.5	17.5	0.141
Northwest	4.5	17.5	0.141

Table 5. Minimum, maximum and daily maximum of air and stream water temperatures °C within the Miramichi Rivers basin at maximum during the summer of 1994.

River	Minimum[1]	Maximum[1]	Difference[2]	Maximum daily mean (date)	
Air Temperature	20.8 °C	28.7	7.9	25.2	(July 22)
Catamaran Bk	18.4	22.3	3.9	21.1	(July 24)
Dungarvon R.	20.3	24.8	4.5	22.4	(July 24)
Little Southwest M.R.	22.0	28.0	6.0	25.0	(July 25)
Southwest M. R.	24.1	26.2	2.1	25.4	(July 26)
Northwest M. R.	24.5	26.0	1.5	25.3	(July 26)

1. These temperatures represent the maximum and minimum recorded temperatures during the maximum daily mean.

2. This value represents the range in temperature (max.-min) during the day of maximum daily mean temperature.

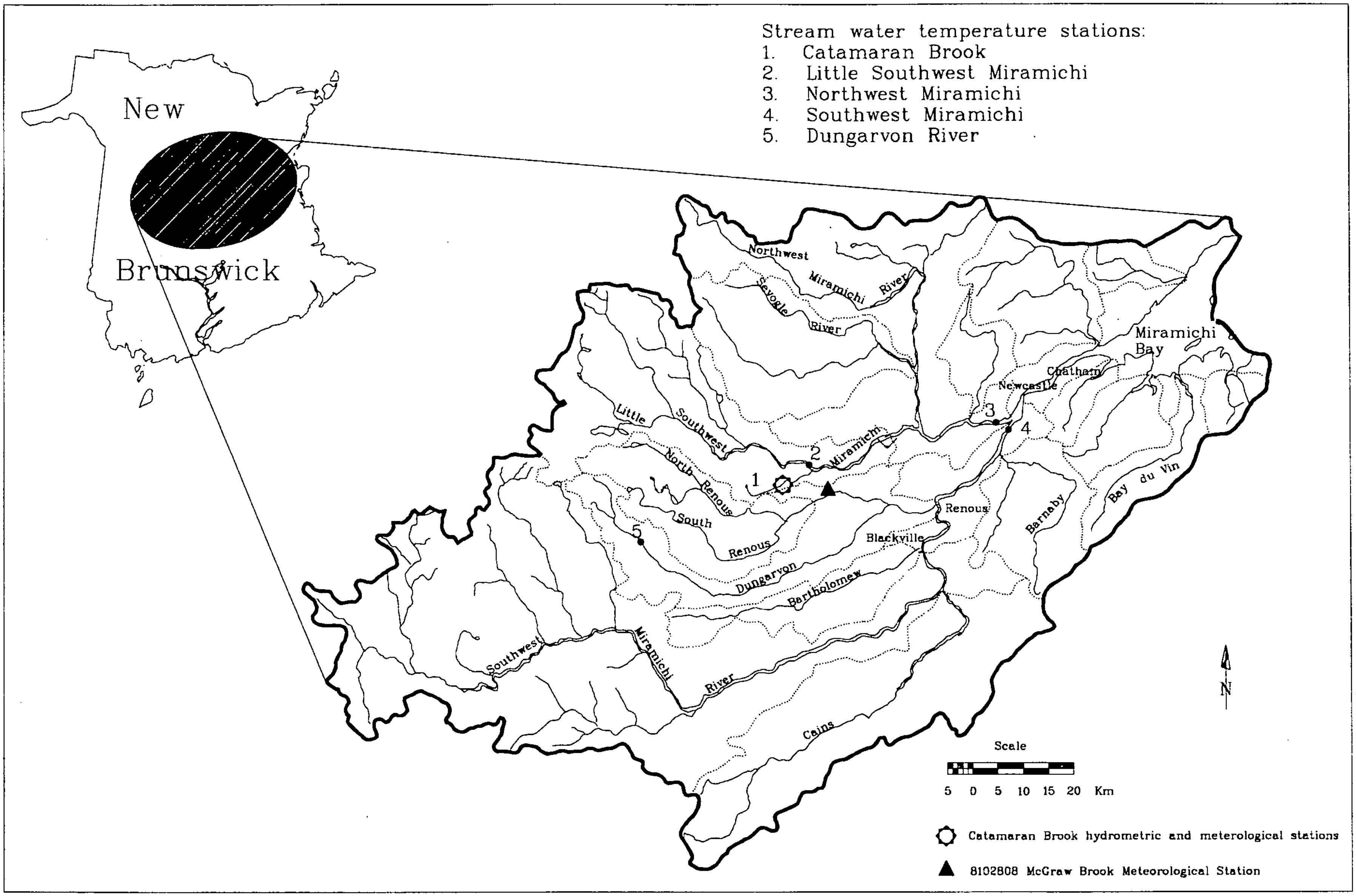

Figure 1. Miramichi River drainage basin showing the location of the hydrometric, meteorological and stream water temperature stations.

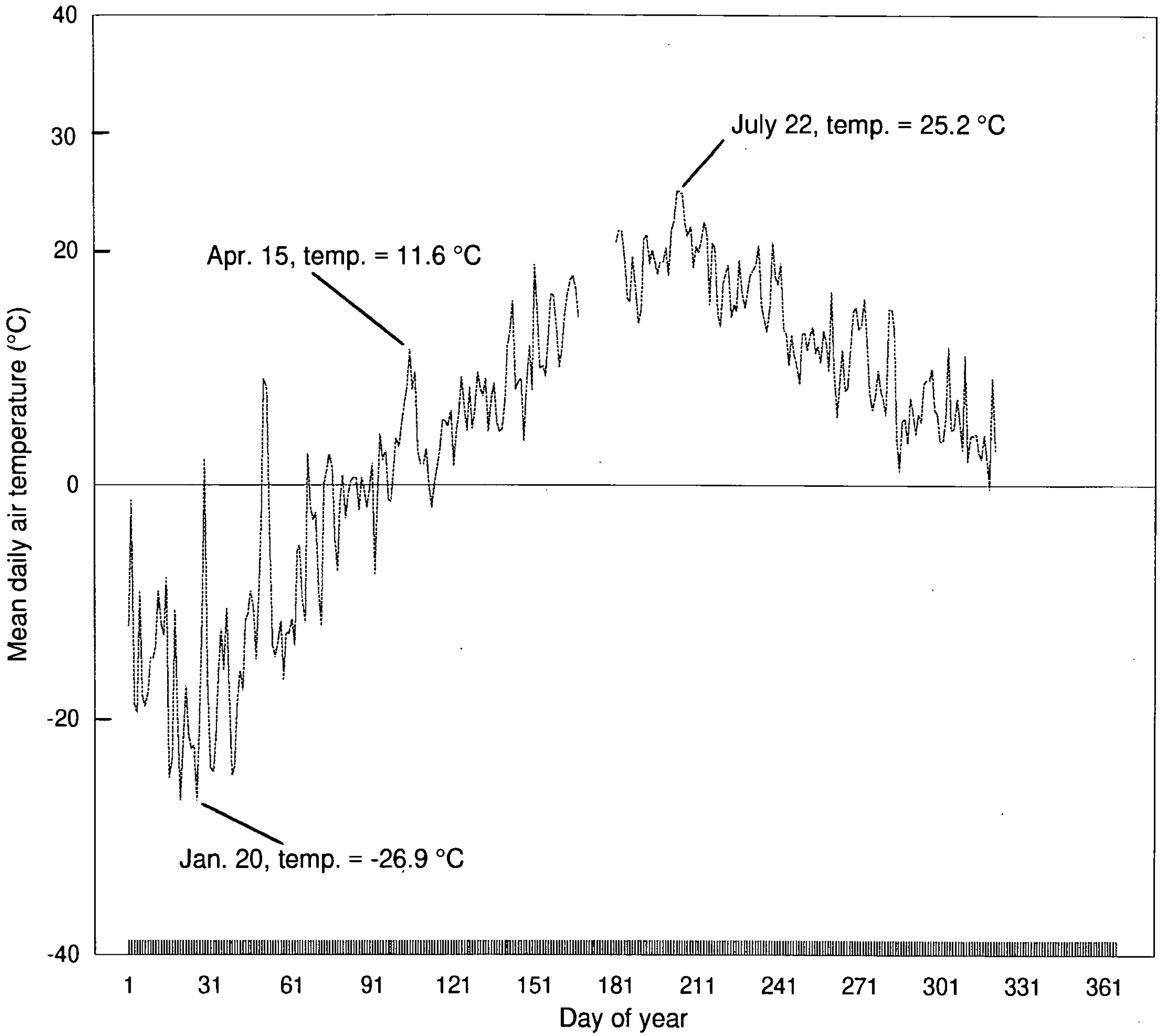

Figure 2. Recorded daily mean air temperature at Catamaran Brook during 1994

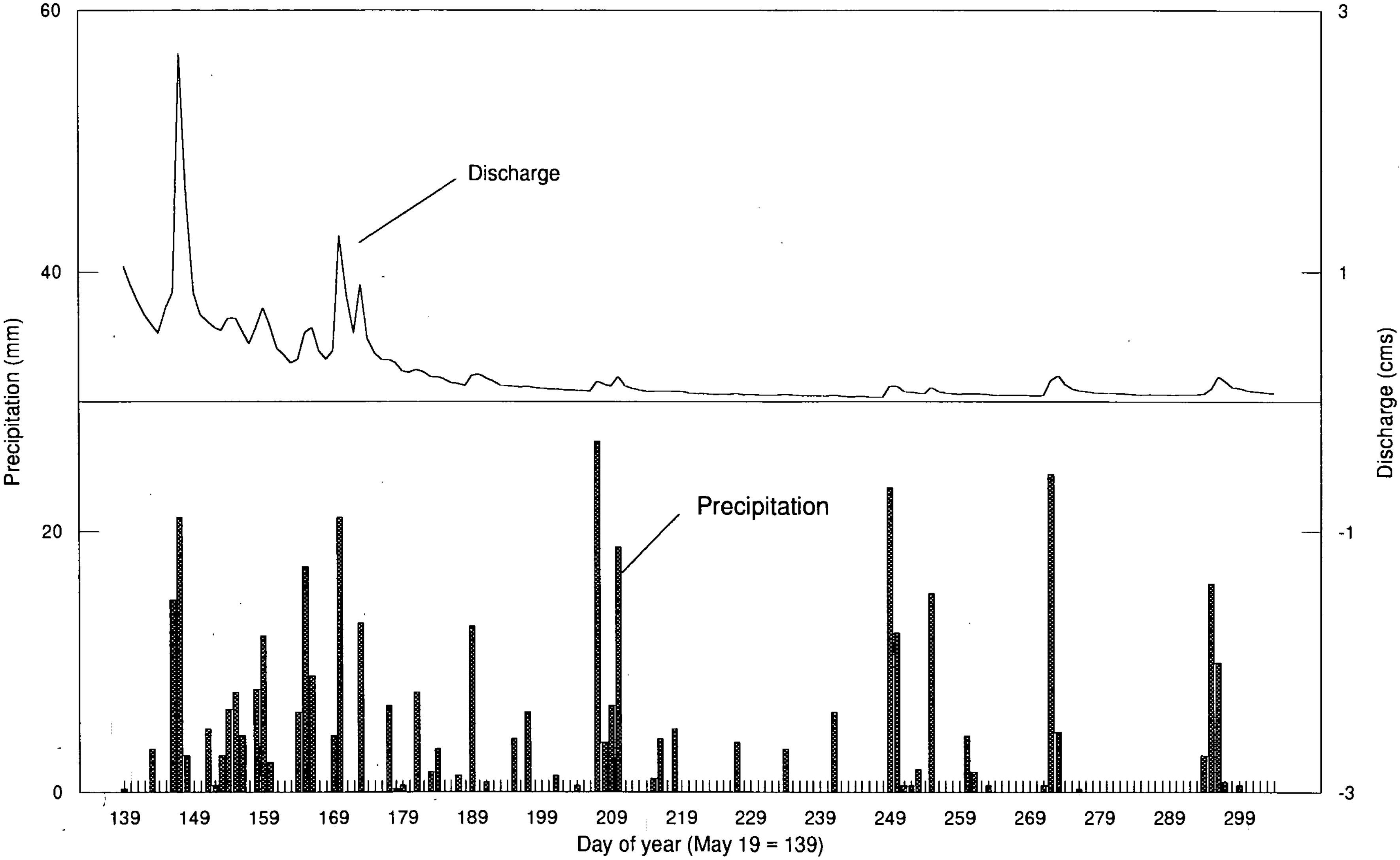

Figure 3. Daily precipitation and discharge in the Middle Reach of Catamaran Brook between May 19 (day 139) and October 31 (day 304), 1994

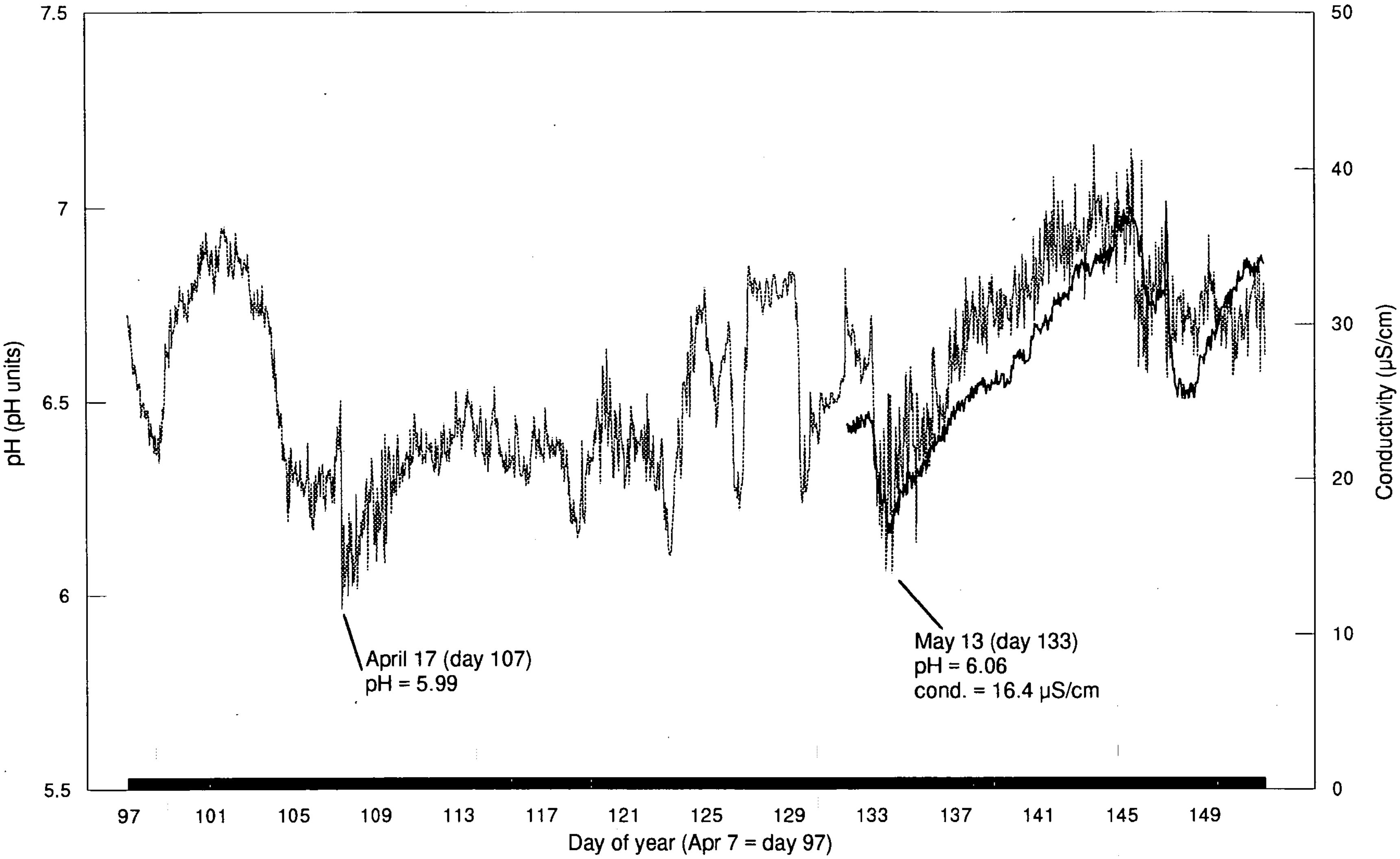

Figure 4. Hourly measurements of pH (dashed line) and conductivity (solid line) at Catamaran Brook during the spring of 1994

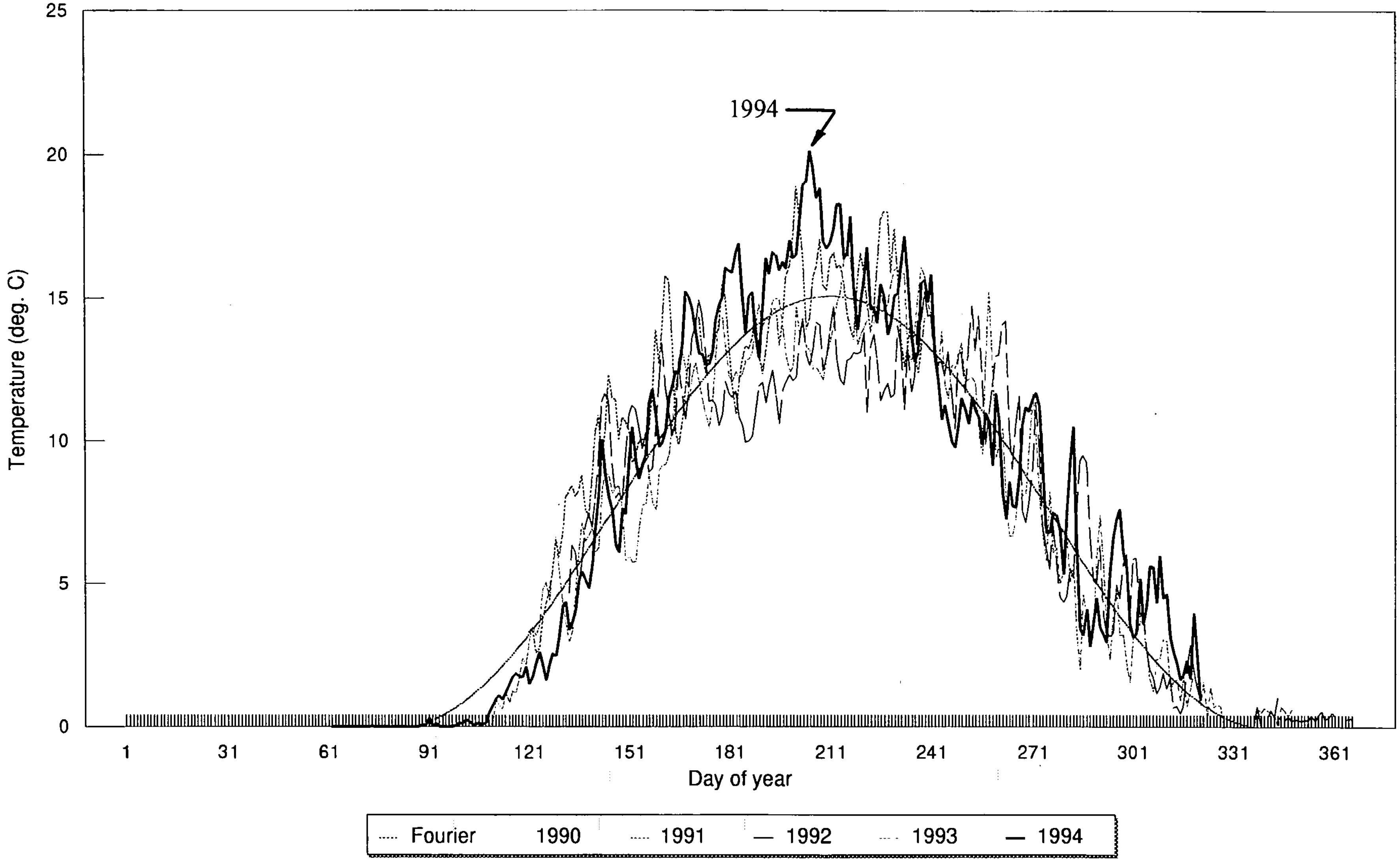

Figure 5. Stream water temperature at Catamaran Brook (Middle Reach) from 1990 to 1994; Fourier series represents long-term temperatures.

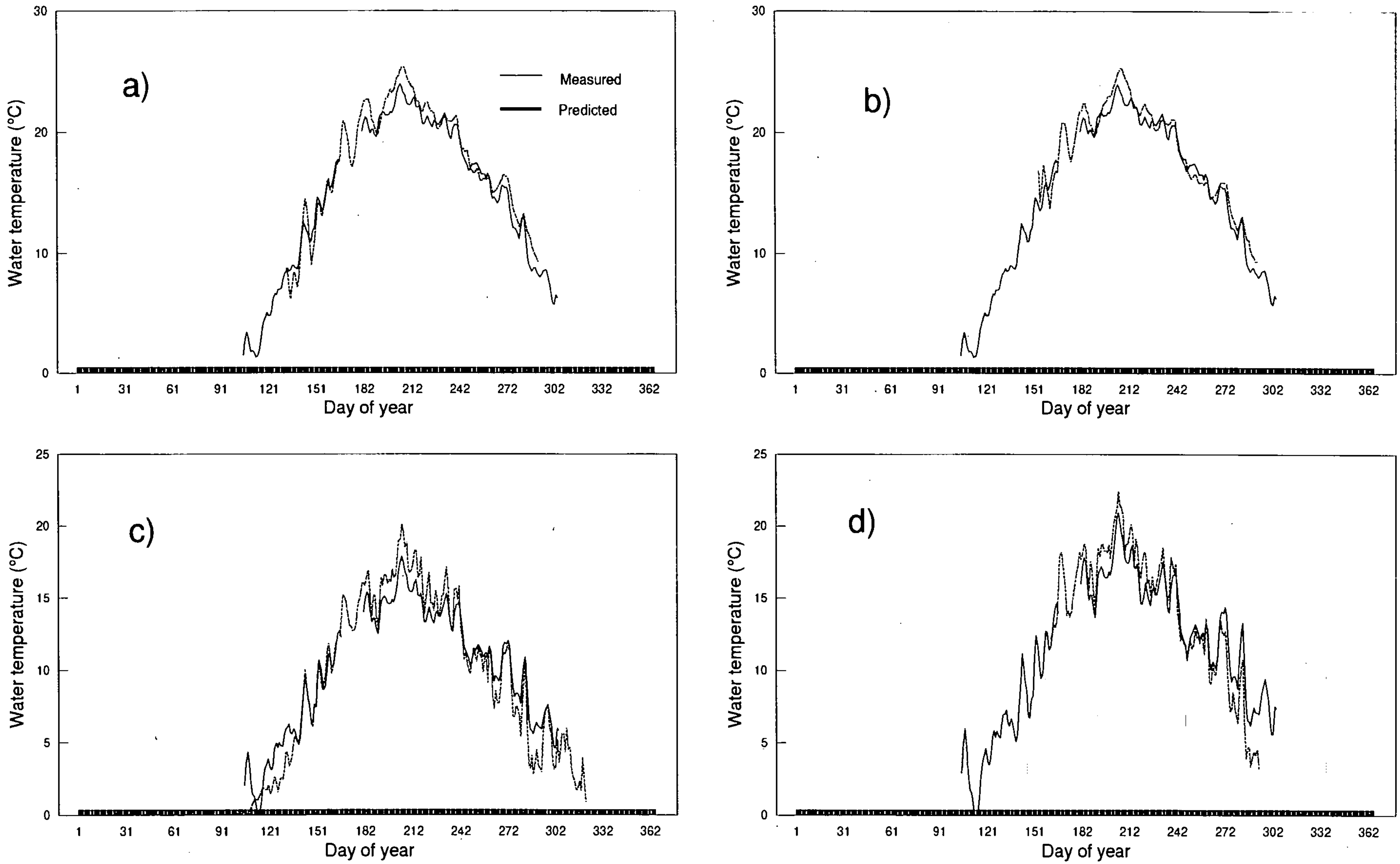

Figure 6. Measured and predicted stream water temperature in the Miramichi River basin during 1994; a) Southwest Miramichi, b) Northwest Miramichi, c) Catamaran Brook, and d) Dungarvon.